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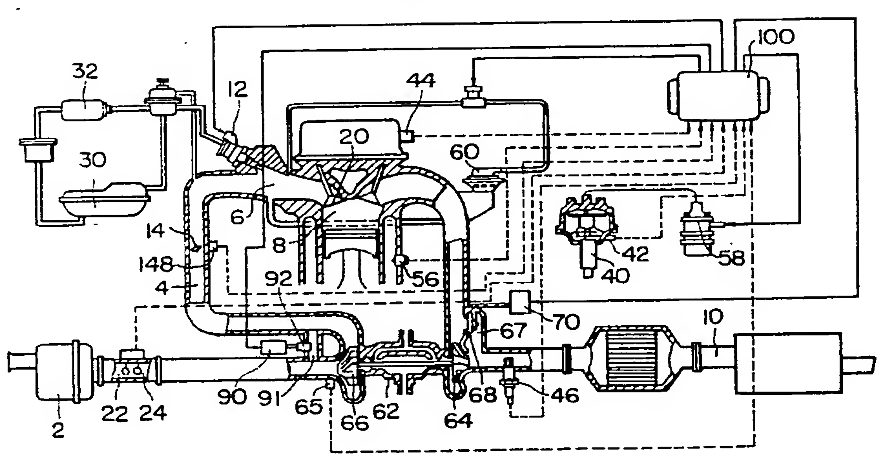
(54) **Control of i.c. engine turbocharging**

(57) A detector (65) detects the speed of rotation of the turbocharger 62, a detector (44) detects whether or not the engine is knocking, and a control circuit (100) incorporating a microcomputer calculates the degress of opening of intake and exhaust by-pass valves (92 and 68) in accordance with a stored program and provides the digital signals for driving by-pass valve actuators (90 and 70). The turbocharger is driven during medium and high-speed operation, as well as acceleration, to thereby increase the engine output, whilst the turbocharger is prevented from constituting a resistance against the intake air flow in the low-speed operation of the engine in which there is no substantial supercharging effect and from overspeeding. An air flow rate sensor (24) and a throttle valve position sensor (148) provide inputs to the control circuit (100) thereby to adjust the turbocharger for acceleration and deceleration.

FIG. 1



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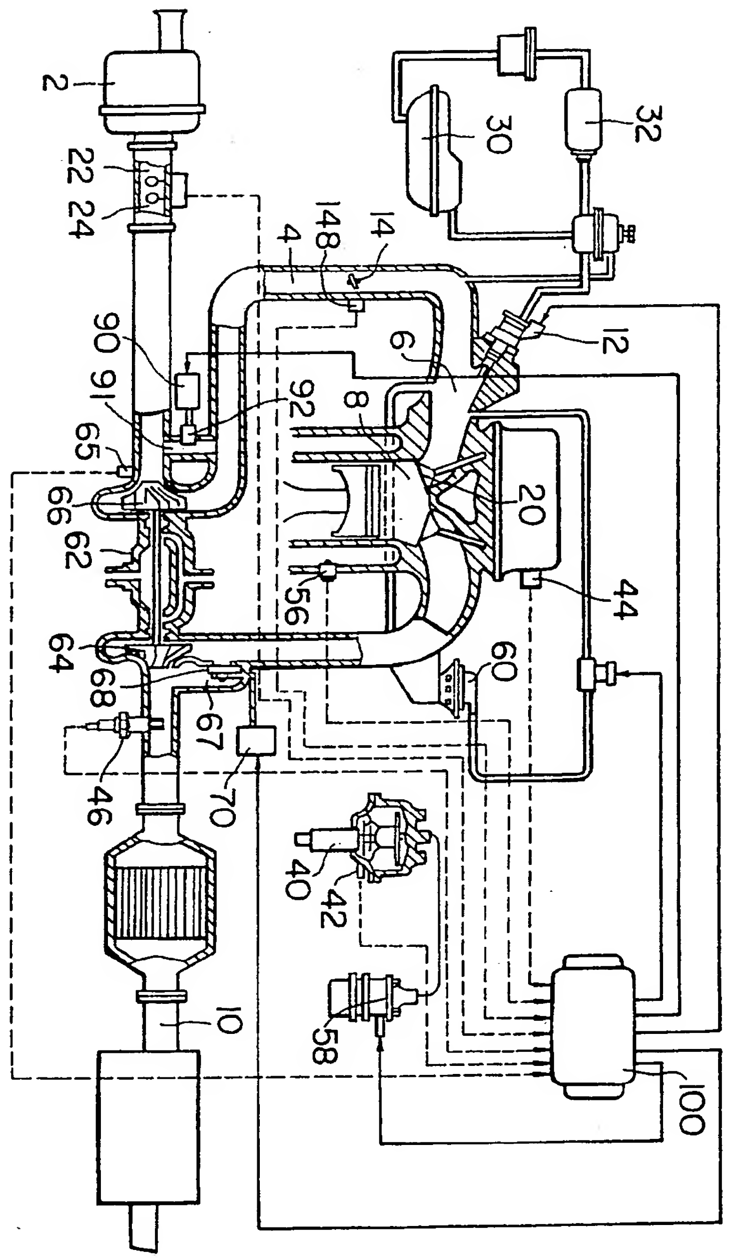

2
22
24
4
148
14
30
32
12
6
90
91
92
8
65
66
62
20
56
44
64
68
67
60
46
70
40
42
58
10
100

FIG. 1

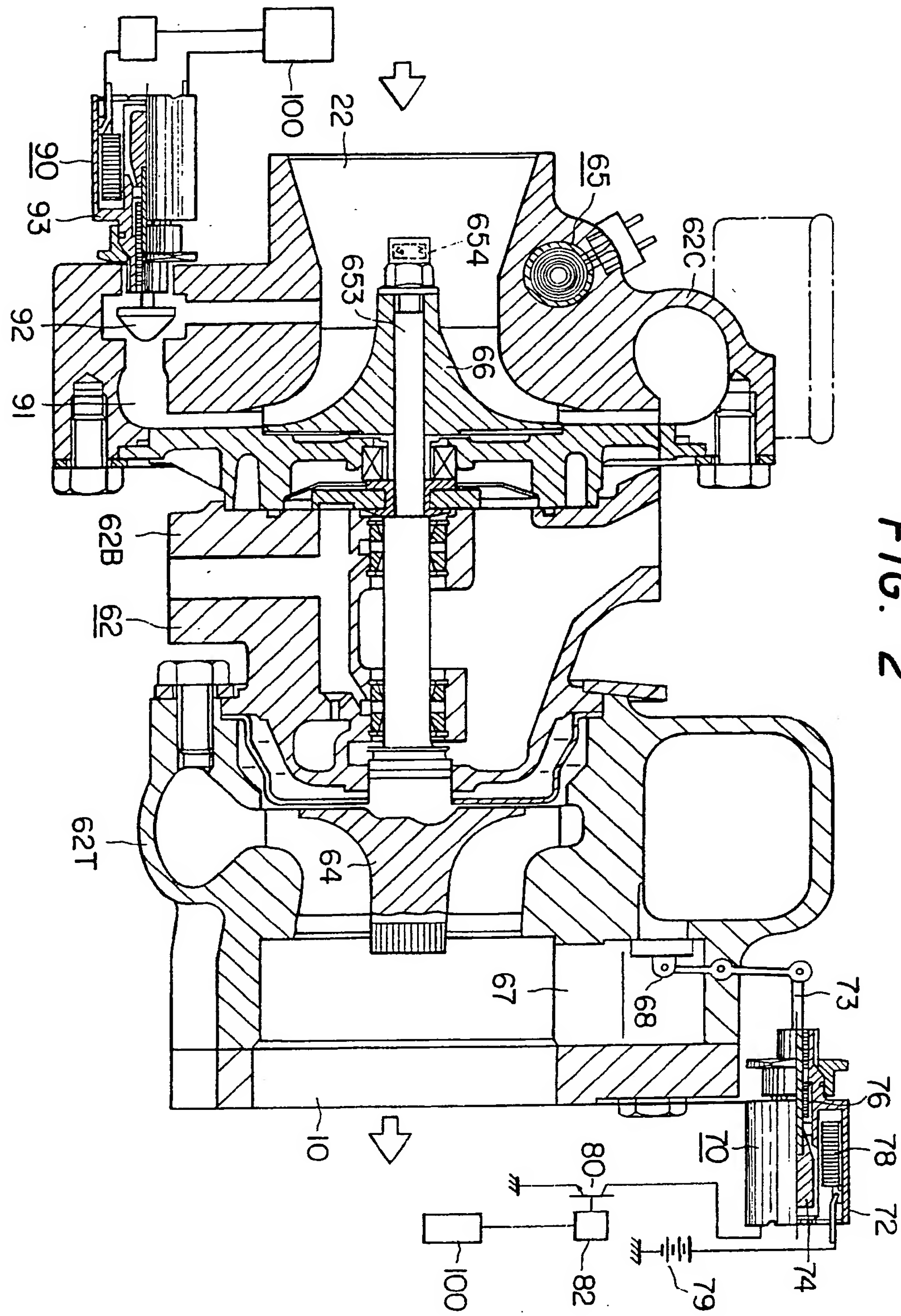

100
22
90
93
654
65
653
62C
92
66
91
62B
62
62T
64
67
68
73
76
70
78
72
74
79
80
82
100
10

FIG. 2

FIG. 3

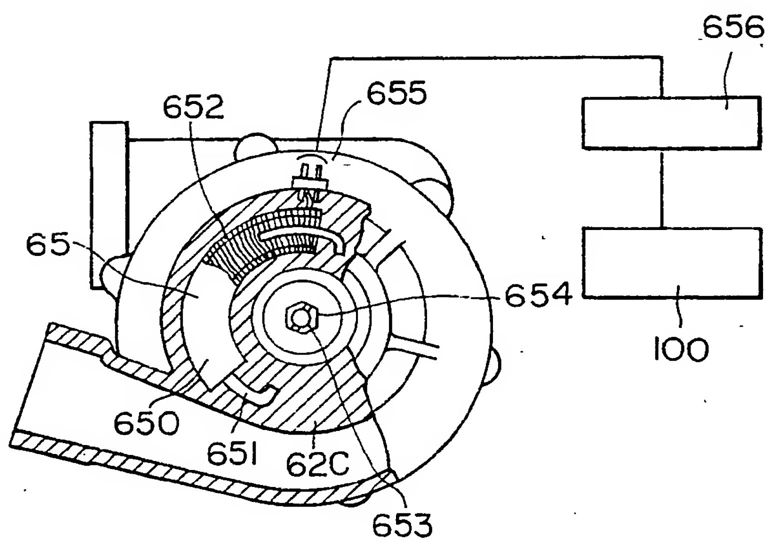


FIG. 4

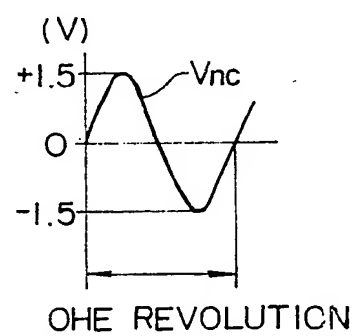


FIG. 12

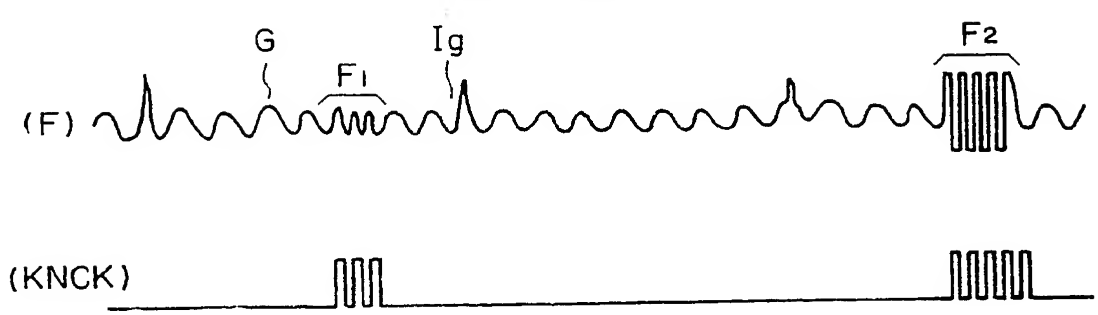


FIG. 5

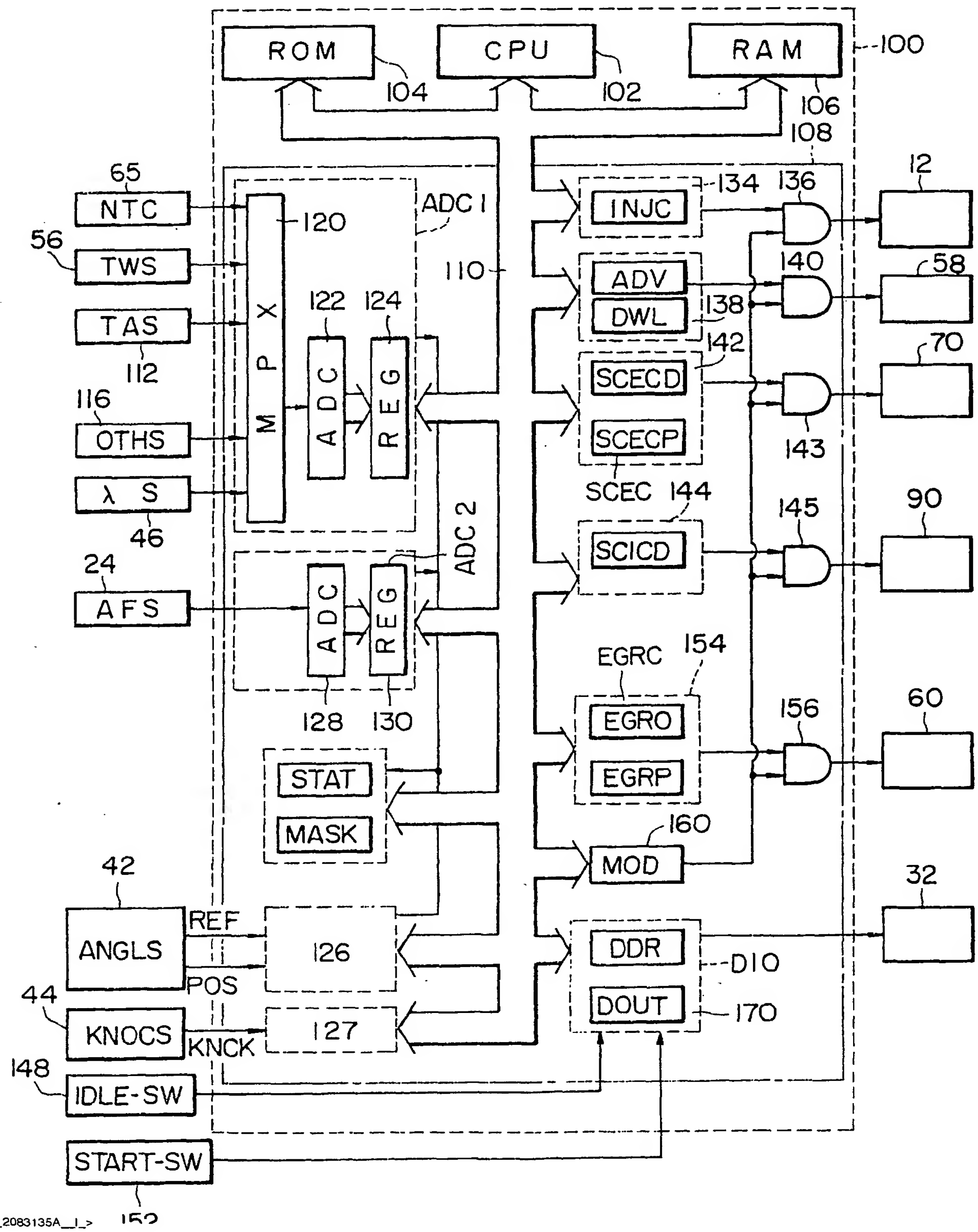

ROM
CPU
RAM
100
104
102
106
108
65
NTC
56
TWS
TAS
112
116
OTHS
λ S
46
24
AFS
MPX
120
ADC I
122
124
ADC
REG
110
ADC 2
128
130
STAT
MASK
INJC
134
136
12
ADV
DWL
138
140
58
142
SCECD
SCECP
143
70
SCEC
144
SCICD
145
90
EGRC
154
EGRO
EGRP
156
60
MOD
160
DDR
DIO
DOUT
170
32
42
ANGLS
REF
POS
126
44
KNOCS
KNCK
127
148
IDLE-SW
START-SW
152

FIG. 6

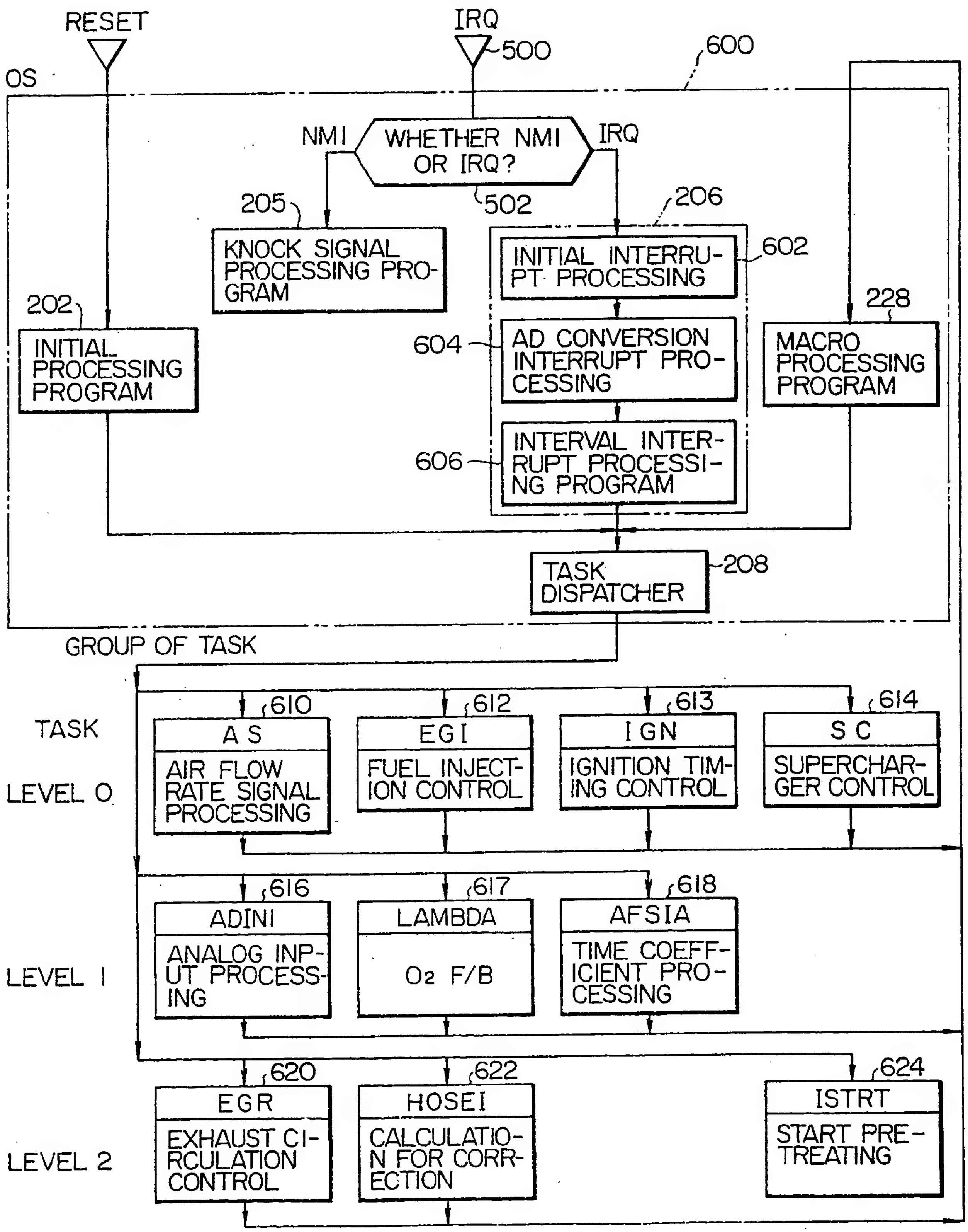

RESET
IRQ
500
600
OS
NMI
WHETHER NMI OR IRQ?
IRQ
502
205
206
KNOCK SIGNAL PROCESSING PROGRAM
INITIAL INTERRUPT PROCESSING
602
202
228
INITIAL PROCESSING PROGRAM
604
AD CONVERSION INTERRUPT PROCESSING
MACRO PROCESSING PROGRAM
606
INTERVAL INTERRUPT PROCESSING PROGRAM
TASK DISPATCHER
208
GROUP OF TASK
TASK
610
612
613
614
AS
AIR FLOW RATE SIGNAL PROCESSING
EGI
FUEL INJECTION CONTROL
IGN
IGNITION TIMING CONTROL
SC
SUPERCHARGER CONTROL
LEVEL 0
616
617
618
ADINI
ANALOG INPUT PROCESSING
LAMBDA
O2 F/B
AFSIA
TIME COEFFICIENT PROCESSING
LEVEL 1
620
622
624
EGR
EXHAUST CIRCULATION CONTROL
HOSEI
CALCULATION FOR CORRECTION
ISTRT
START PRETREATING
LEVEL 2

FIG. 7

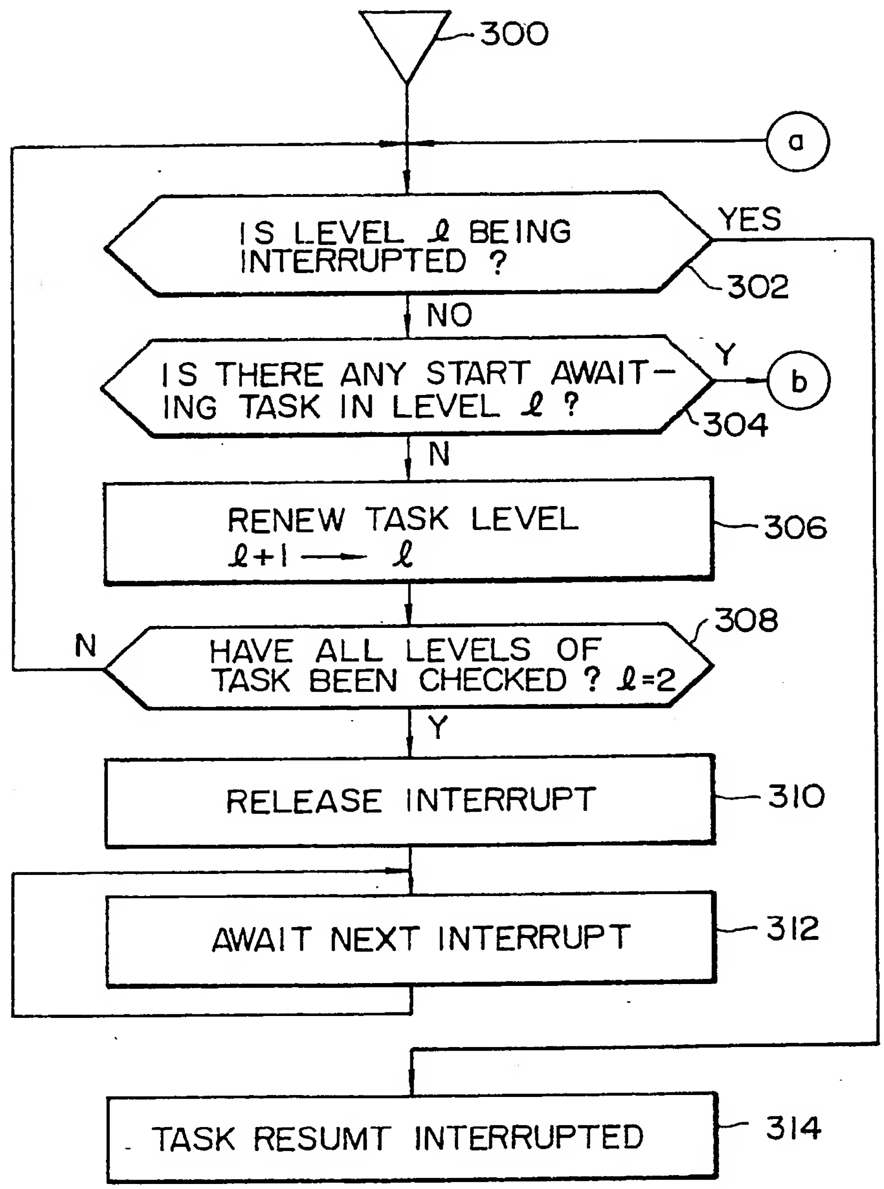

300
a
IS LEVEL ℓ BEING INTERRUPTED ?
YES
302
NO
IS THERE ANY START AWAIT-ING TASK IN LEVEL ℓ ?
Y
b
304
N
RENEW TASK LEVEL ℓ+1 → ℓ
306
308
N
HAVE ALL LEVELS OF TASK BEEN CHECKED ? ℓ=2
Y
RELEASE INTERRUPT
310
AWAIT NEXT INTERRUPT
312
TASK RESUMT INTERRUPTED
314

FIG. 8

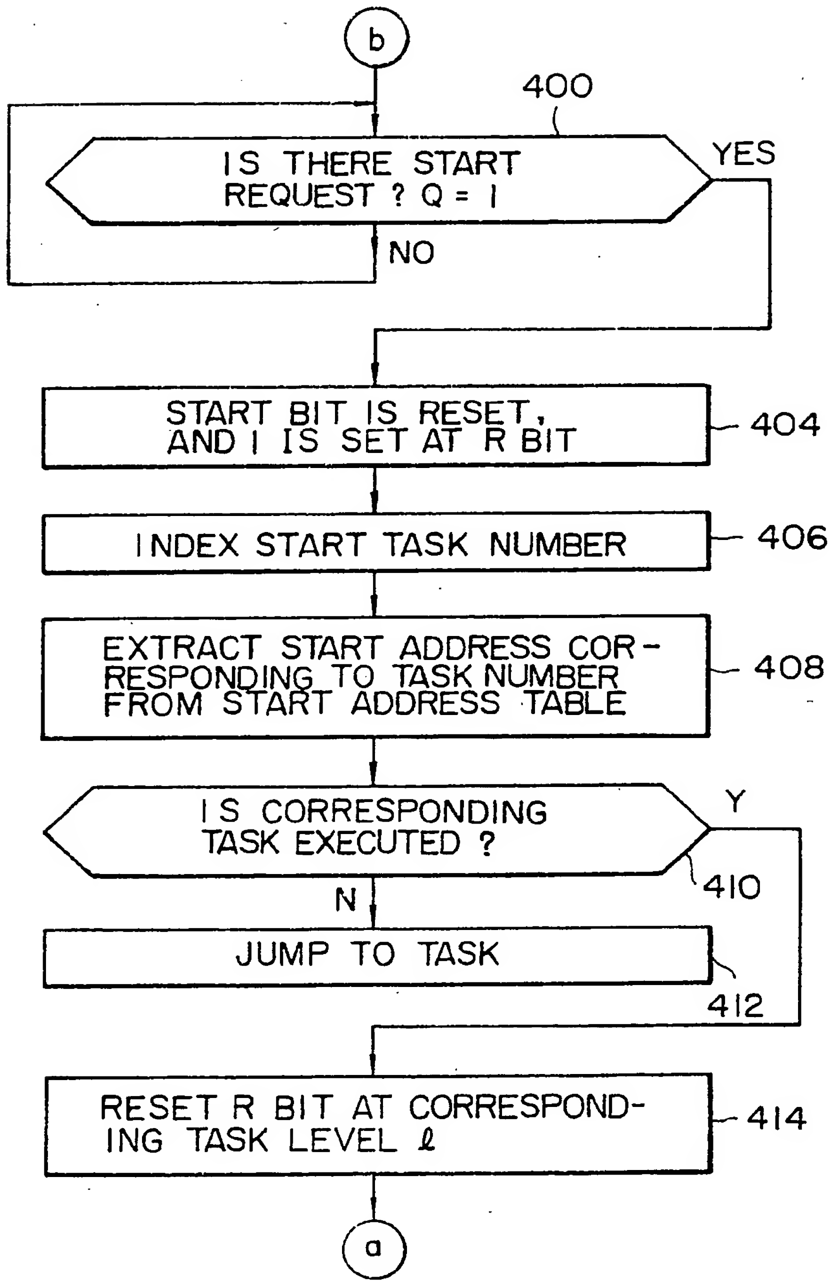

b
400
IS THERE START REQUEST ? Q = 1
YES
NO
START BIT IS RESET, AND 1 IS SET AT R BIT
404
INDEX START TASK NUMBER
406
EXTRACT START ADDRESS CORRESPONDING TO TASK NUMBER FROM START ADDRESS TABLE
408
IS CORRESPONDING TASK EXECUTED ?
Y
N
410
JUMP TO TASK
412
RESET R BIT AT CORRESPONDING TASK LEVEL ℓ
414
a

FIG. 9

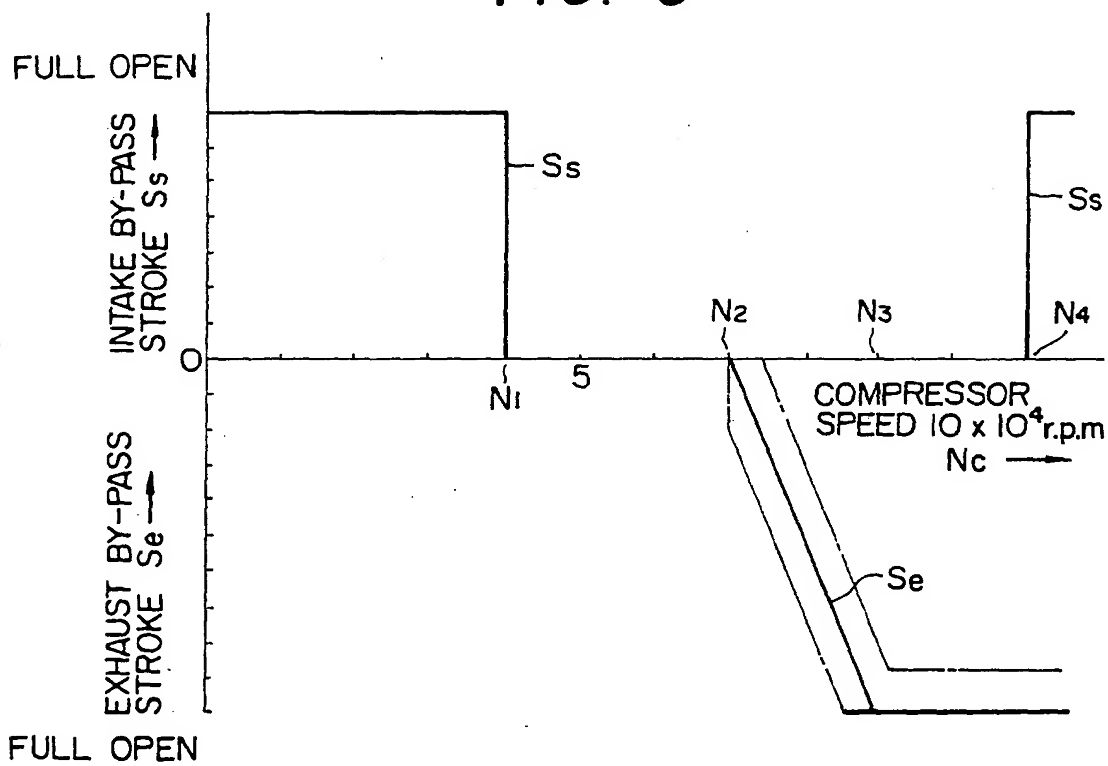

FULL OPEN
INTAKE BY-PASS STROKE Ss
Ss
Ss
O
N1
5
N2
N3
N4
COMPRESSOR SPEED 10 x 10⁴ r.p.m
Nc
EXHAUST BY-PASS STROKE Se
Se
FULL OPEN

FIG. 10

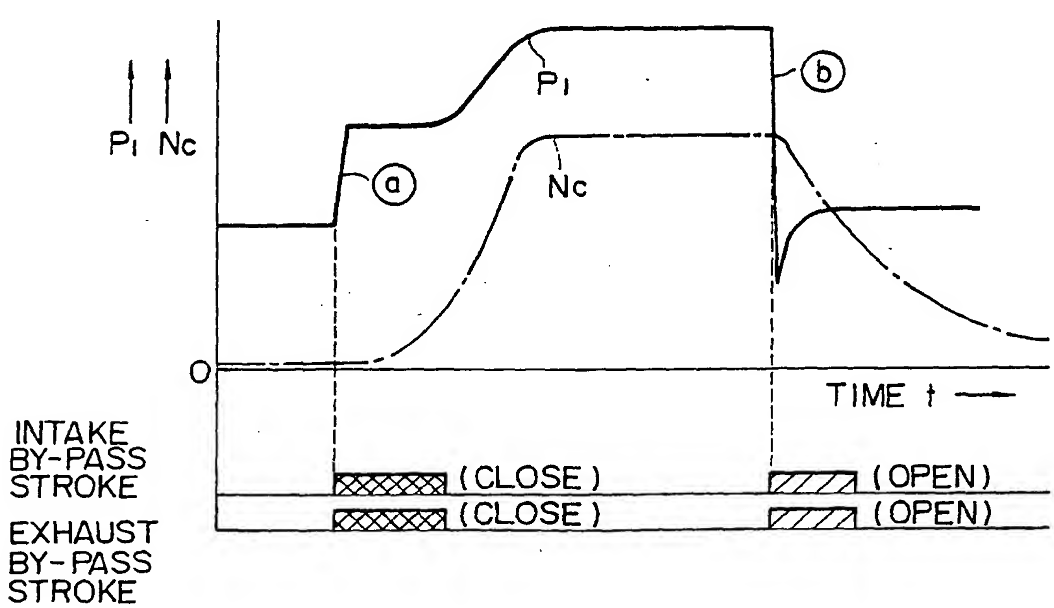
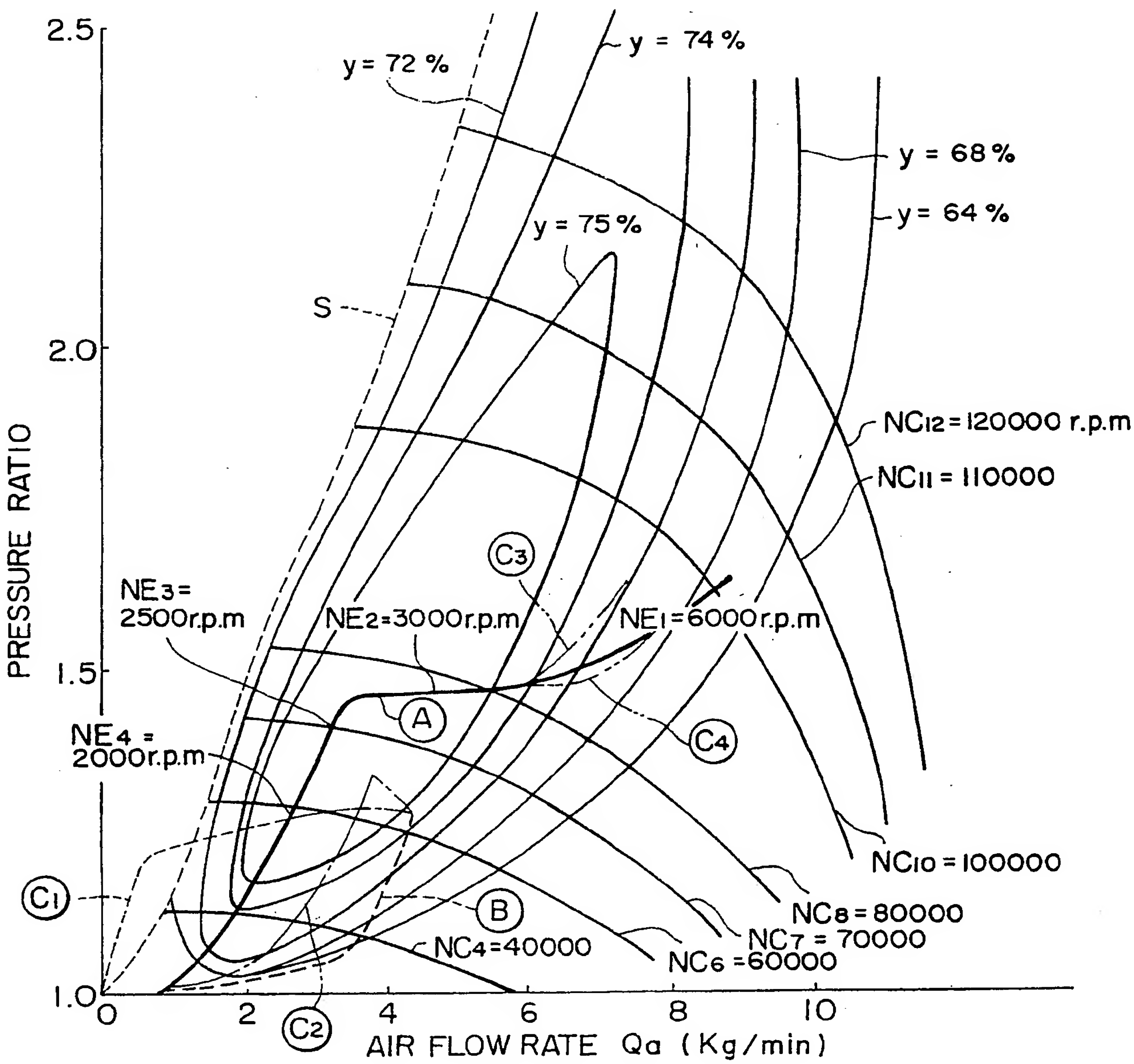

P1 Nc
P1
Nc
a
b
O
TIME t
INTAKE BY-PASS STROKE
(CLOSE)
(OPEN)
EXHAUST BY-PASS STROKE
(CLOSE)
(OPEN)

FIG. 11



2.5
2.0
1.5
1.0
PRESSURE RATIO
0
2
4
6
8
10
AIR FLOW RATE Qa (Kg/min)
y = 72 %
y = 74 %
y = 68 %
y = 64 %
y = 75 %
S
NC12 = 120000 r.p.m
NC11 = 110000
NC10 = 100000
NC8 = 80000
NC7 = 70000
NC6 = 60000
NC4 = 40000
NE3 = 2500r.p.m
NE2 = 3000r.p.m
NE1 = 6000r.p.m
NE4 = 2000r.p.m
A
B
C1
C2
C3
C4

FIG. 13

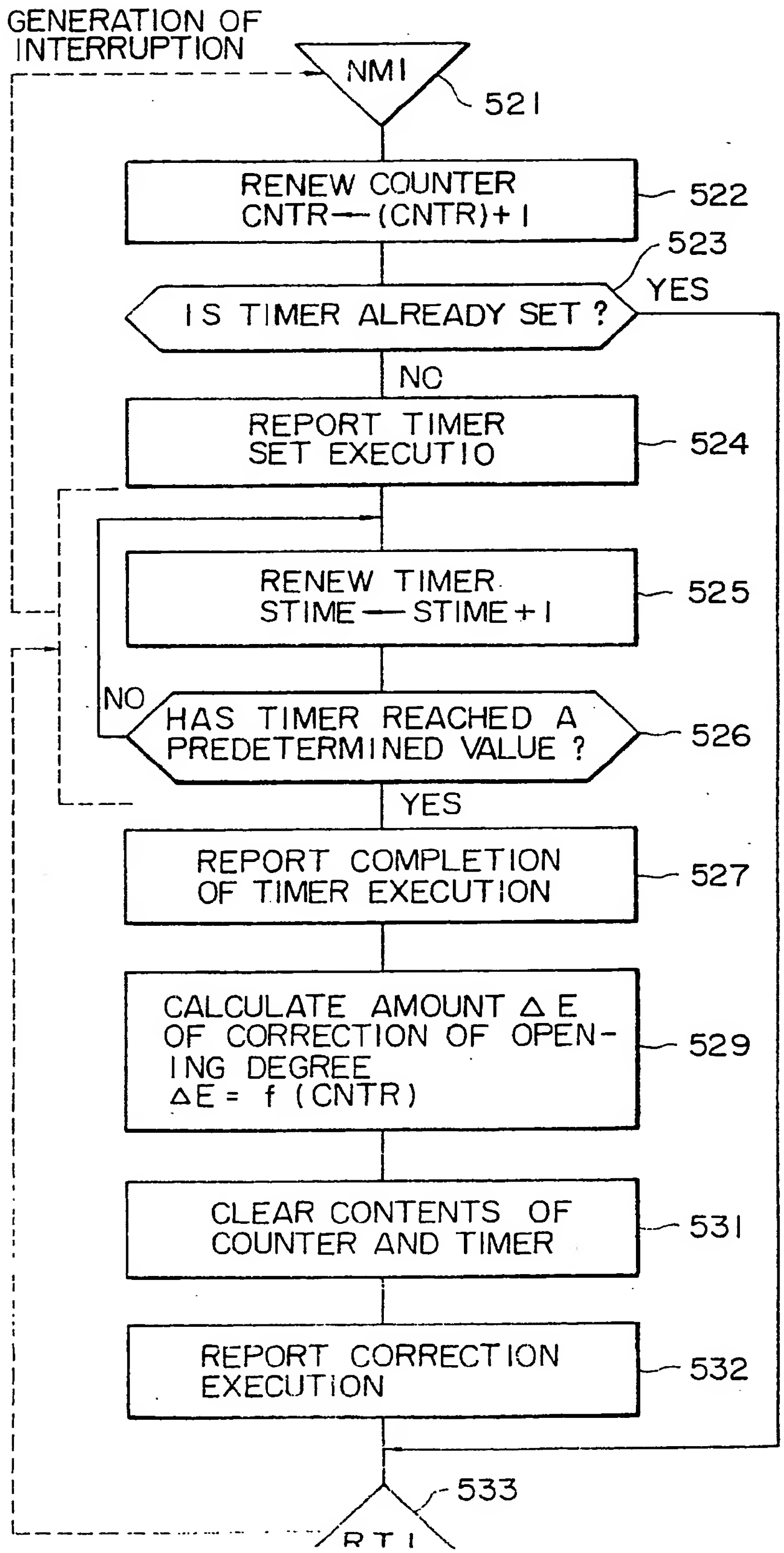
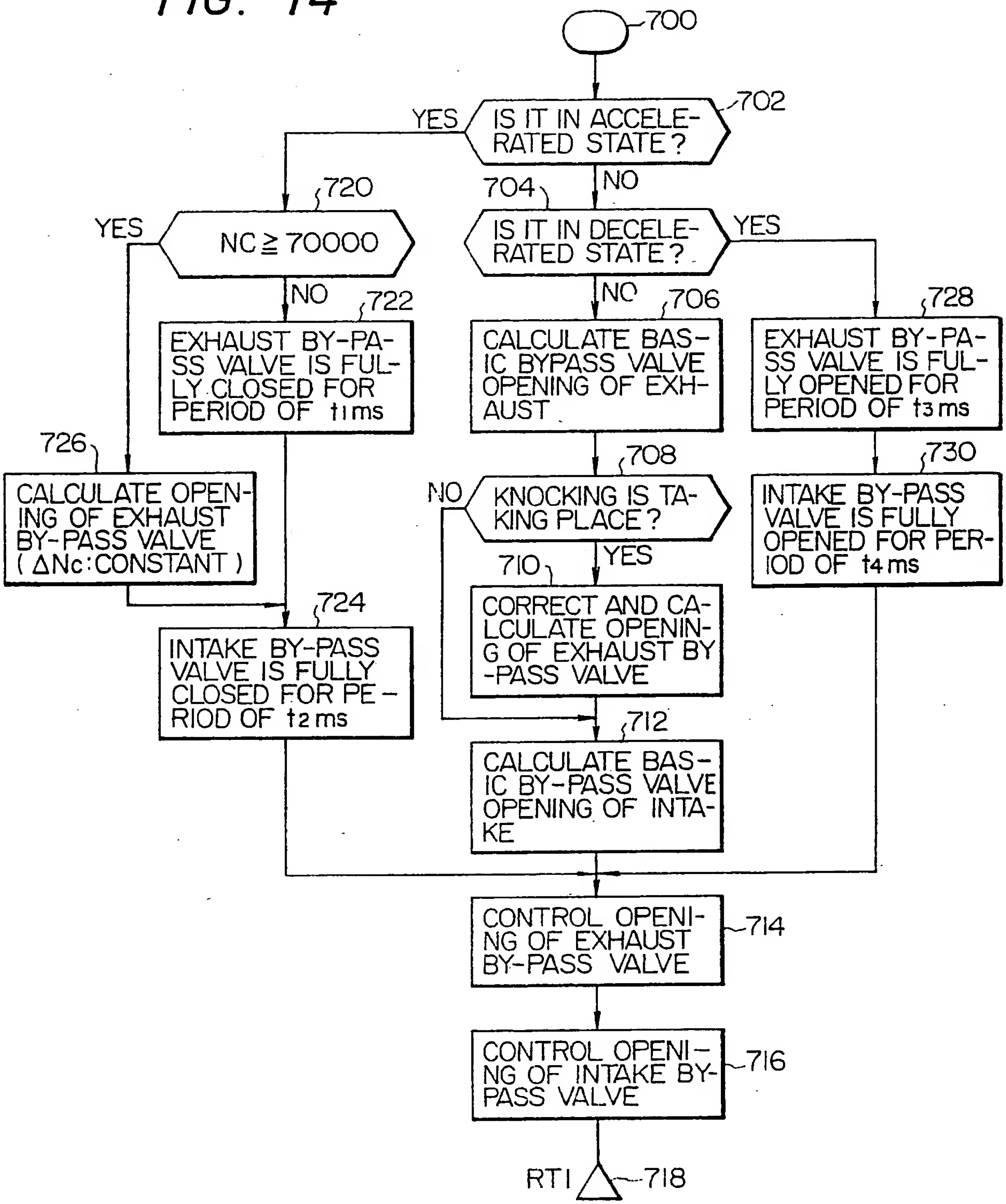

GENERATION OF INTERRUPTION
NMI
521
RENEW COUNTER
CNTR ← (CNTR)+1
522
523
YES
IS TIMER ALREADY SET ?
NO
REPORT TIMER SET EXECUTIO
524
RENEW TIMER
STIME ← STIME+1
525
NO
HAS TIMER REACHED A PREDETERMINED VALUE ?
526
YES
REPORT COMPLETION OF TIMER EXECUTION
527
CALCULATE AMOUNT ΔE OF CORRECTION OF OPENING DEGREE
ΔE = f (CNTR)
529
CLEAR CONTENTS OF COUNTER AND TIMER
531
REPORT CORRECTION EXECUTION
532
533
RTI

FIG. 14


700
IS IT IN ACCELERATED STATE?
702
YES
NO
704
IS IT IN DECELERATED STATE?
YES
NO
720
NC ≧ 70000
YES
NO
722
EXHAUST BY-PASS VALVE IS FULLY CLOSED FOR PERIOD OF t1 ms
706
CALCULATE BASIC BYPASS VALVE OPENING OF EXHAUST
728
EXHAUST BY-PASS VALVE IS FULLY OPENED FOR PERIOD OF t3 ms
726
CALCULATE OPENING OF EXHAUST BY-PASS VALVE (ΔNc:CONSTANT)
708
NO
KNOCKING IS TAKING PLACE?
YES
730
INTAKE BY-PASS VALVE IS FULLY OPENED FOR PERIOD OF t4 ms
710
CORRECT AND CALCULATE OPENING OF EXHAUST BY-PASS VALVE
724
INTAKE BY-PASS VALVE IS FULLY CLOSED FOR PERIOD OF t2 ms
712
CALCULATE BASIC BY-PASS VALVE OPENING OF INTAKE
CONTROL OPENING OF EXHAUST BY-PASS VALVE
714
CONTROL OPENING OF INTAKE BY-PASS VALVE
716
RTI
718

SPECIFICATION

A supercharger control apparatus

The present invention relates to an apparatus for controlling a supercharger for internal combustion engines and, more particularly, to an apparatus for controlling a supercharger having an intake by-pass valve and an exhaust by-pass valve.

In order to improve fuel consumption and output characteristics of internal combustion engines, the use of a supercharger employing a compressor driven by the energy possessed by the exhaust gas has been found effective. Supercharging is usually adopted in order to increase the engine output during the high-speed operation of the engine. In some cases, however, supercharging is used to compensate for a shortage of torque in medium and low speed operation ranges of the engine. In these cases, there is the danger that the supercharging pressure may become excessively high so as to cause damage to the engine.

In order to avoid this problem, it has been proposed to use a by-pass valve for by-passing part of the exhaust gas supplied to the exhaust gas turbine in order to suppress an increase in supercharging pressure during high-speed operation of the engine. In this case as disclosed in the specification of U.S. Patent No. 4,120,156, the exhaust by-pass valve is opened by the force produced by the supercharging pressure. Thus, this control of the supercharging pressure is carried out only during high-speed operation of the engine. In the specification of U.S. Patent No. 4,207,743 there is described a system wherein an intake by-pass valve which communicates with the suction and delivery sides of the compressor during acceleration is employed. The by-pass valves described in these patent systems are intended for operation only in specific conditions of engine operation. Using such mechanisms it would be difficult and require a complicated mechanism to produce a system operable in response to all states of engine operation by aggregating these by-pass valves.

According to the present invention there is provided a supercharger control apparatus for use with an exhaust gas turbine system driven by the energy of the exhaust gas from an internal combustion engine and being coupled with a supercharger compressor driven by said turbine, and which is coupled to a fluid intake system of the engine to supercharge the engine, the system having a controllable exhaust gas by-pass mechanism for controlling the supply of exhaust gas to said turbine; said supercharger control apparatus including:

(a) first means for monitoring the operation of said engine;
(b) second means for monitoring a prescribed operational characteristic of said supercharger;
(c) third means for storing data representative of the degree to which said exhaust by-pass mechanism by-passes exhaust gas from said turbine in relation to the state of operation of said engine and said supercharger;
(d) fourth means, coupled to said first, second and third means, for generating control signals for controlling the operation of said exhaust gas by-pass mechanism in response to data stored by said third means and accessed in accordance with outputs of said first and second means; and
(e) fifth means for coupling control signals generated by said fourth means to said exhaust gas by-pass mechanism and thereby control the supply of exhaust gas to said turbine.

Thus, it is possible to control the supercharger in accordance with the condition of operation of the engine, by making efficient use of a microcomputer. In particular, the intake loss during the low speed operation of the engine is reduced whilst attaining a high supercharging gain in the high-speed operation of the engine.

In addition, it is possible to improve the acceleration performance and to protect the supercharger and engine during deceleration.

Moreover, since the control relies upon a feedback control upon detection of the revolution speed of the supercharger, it is possible to detect accurately and with a good response time the state of the supercharger over the entire region of engine operation to attain the expected characteristic of control, as compared with a conventional system in which the control is based upon detection of the supercharging pressure.

The present invention will now be described in greater detail by way of example with reference to the accompanying drawings, wherein:-

Figure 1 shows a preferred form of control system for controlling a supercharger of an internal combustion engine;

Figure 2 is a sectional view showing details of the supercharger in the system shown in Figure 1;

Figure 3 shows details of a detector for detecting the revolution speed of the supercharger in the system shown in Figure 1;

Figure 4 is a graph illustrating the output of the detector shown in Figure 3;

Figure 5 is a block circuit diagram showing details of the control circuit as shown in Figure 1;

Figure 6 is a flow chart showing the basic arrangement of the program system;

Figures 7 and *8* are flow charts illustrating the process flow of the task dispatcher;

Figure 9 is a graph illustrating the control characteristic of the supercharger in relation to engine revolution speed;

Figure 10 is a graph illustrating the controlling characteristics for intake by-pass valve and exhaust by-pass valve during acceleration and deceleration;

Figure 11 is a graphical map illustrating the operation characteristic of a compressor, for explaining the

controlling characteristic during acceleration and deceleration;

Figure 12 shows two waveforms which illustrate the output from a knock sensor;

Figure 13 is a flow chart showing the flow of the processing of the knock signal; and

Figure 14 is a flow chart showing the flow of the processing of control of the supercharger.

Figure 1 shows the overall structure of a spark ignition internal combustion engine (hereinafter referred to simply as "engine"). Referring to Figure 1, intake air is supplied to a cylinder 8 through an air filter 2, throttle chamber 4 and an intake pipe 6, whilst exhaust gas generated as a result of combustion in the cylinder 8 is discharged into the atmosphere through an exhaust pipe 10.

The throttle chamber 4 is provided with an injector 12 for injecting fuel to form an air-fuel mixture which is supplied to the combustion chamber in the cylinder 8 as an intake valve 20 opens. The fuel is supplied from a fuel tank 30 to the injector 12 through a fuel pump 32.

An air passage 22 is formed at the upstream side of a throttle valve 14 in the throttle chamber 4. A hot wire element 24 constituting a thermal type air flow meter is located in the air passage 22. This hot wire element 24 produces an electric signal which changes in accordance with the change in the flow velocity of air, i.e. determined by the relationship between the rate of cooling effected by the flowing air and the rate of generation of heat by the hot wire element 24. The fully closed state of throttle valve 14 is detected by a throttle sensor 148.

A distributor 40 is provided with a crank angle sensor 42 adapted to produce, respectively, a reference angle signal at a predetermined reference crank angle and a position signal at a constant crank angle interval, e.g. 0.5°.

A knock sensor 44 attached to the cylinder 8 is adapted to detect abnormal ignition, i.e. knocking, in the engine.

A control circuit 100 consisting of a microcomputer is provided to carry out arithmetic operations upon receipt of various signals such as the outputs from the hot wire element 24, knock sensor 44, λ sensor 46, crank angle sensor 42, cooling water temperature sensor 56, and the output from a compressor rotation speed detector 65 which will be described later. The injector 12 and an ignition coil 58 are activated in accordance with the outputs from the control circuit 100. A spark plug (not shown) in the cylinder 8 is supplied with a high voltage by the distributor 40 in accordance with the ignition timing. An exhaust gas recirculation control valve 60 is provided as shown; this valve hereinafter being referred to as "EGR valve".

In order to improve the fuel consumption and to increase the engine output through the recovery of the energy discharged in the exhaust gas, the engine incorporates a supercharger 62 arranged in the intake and exhaust systems. The supercharger 62 includes a turbine 64 adapted to be driven by the exhaust gas from the engine so as to drive a compressor 66 mounted on the same shaft as the turbine 64 to thereby supercharge the engine. The pressure of the supercharged air is determined by the revolution speed of the turbine 64 and the flow rate of the air. An excessively high supercharging pressure may cause a breakdown of the engine, while a too low pressure may cause an increase in fuel consumption and reduction of engine output.

In order to effect an optimum control of the supercharger, an exhaust by-pass passage 67 is provided, so as to control the rate of introduction of the exhaust gas to the turbine 64 of the supercharger 62. The exhaust by-pass passage 67 is arranged to be opened and closed by an exhaust by-pass valve 68 which, in turn, is controlled by an actuator 70.

An intake by-pass passage 91 is provided on the compressor side of the supercharger 62. This passage 91 is arranged to be opened and closed by an intake by-pass valve 92 which, in turn, is actuated by an actuator 90. Also, a compressor speed detector 65 is provided for detecting the speed of rotation of the compressor 66.

Referring now to the details of the supercharger and the control mechanism shown in Figure 2, the supercharger 62 has a compressor block 62C, bearing block 62B and a turbine block 62T. The actuator 70 for actuating the exhaust by-pass valve 68 includes a solenoid 72 and a connecting rod 73. The solenoid 72 has a plunger 74 which is normally biased by a spring 76 so as to close the exhaust by-pass passage 68.

A transistor 80 is arranged between an electromagnetic coil 78 and a voltage source 79. For a pulse current of a high frequency, having a period of an order of 10 m sec applied to the base electrode of the transistor 80, the stroke of the plunger 74 is determined in accordance with the ratio of the length of time in which the pulse current is supplied in each cycle to the time length of one cycle T_{ON}/T. This ratio will hereinafter be referred to as the "on-duty". The on-duty is calculated by the control circuit 100. An amplifier 82 is provided between the control circuit 100 and the base electrode of the transistor 80.

The actuator 90 for actuating the intake by-pass valve 92 is provided with a solenoid 93 of similar construction to that of the actuator 70, and is controlled by the output from the control circuit 100.

Referring to Figure 3, the compressor speed detector 65 includes a core 651 mounted in a cavity 650 formed in the compressor block 62C, a coil 652 wound around the core 651 and a permanent magnet 654 fixed to the shaft 653 of the supercharger. The signal delivered from th terminals 655 of the coil 652 is amplified by an RC resonance circuit 656 to provide an output waveform Vnc as shown in Figure 4. It should be noted that it is possible to obtain a sine wave output having a frequency which is directly proportional to the speed of rotation of the supercharger. This output is shaped into a pulse signal and delivered to the control circuit 100.

Referring now to Figure 5 the control circuit 100 includes a CPU (Central Processing Unit) 102, read-only

memory 104 (ROM), random access memory 106 (RAM) and an input/output circuit 108. The CPU 102 carries out arithmetic operations on the basis of the input data input through the input/ouput circuit 108 in accordance with various programs stored in the ROM 104, and returns the result of the calculations to the input/output circuit 108. The intermediate memory necessary for the arithmetic operations is stored in the RAM 106. The exchange of data between the units comprising CPU 102, ROM 104, RAM106 and input/output circuit 108 is conducted through a BUS line 110 which includes a data BUS, a control BUS and an address BUS.

The input/output circuit 108 includes input means containing a first analog-to-digital converter (ADC_1), a second analog-to-digital converter (ADC_2), an angle signal processing circuit 126 and a discrete input/output circuit (DIO) 170 for inputting and outputting 1-bit data.

A multiplexer 120 (MPX) receives output signals from cooling water temperature sensor 56 (TWS), air temperature sensor 112 (TAS), throttle valve angle sensor 116 (θTHS), λ sensor 46 (λS) and a supercharger speed sensor 65 (NTc). The multiplexer 120 selects one of these output signals and delivers the same to an analog-to-digital conversion circuit 122 (ADC) the digital output from which is coupled to a register 124 (REG) and stored by the latter.

The output from the hot wire element 24 (AFS) is supplied to the analog-to-digital converter ADC2, and is converted into a digital signal through an analog-to-digital conversion circuit 128 (ADC) and is stored in a register 130 (REG). The crank angle sensor 42 (ANGS) delivers to the angle signal processing circuit 126 a reference crank angle signal (REF) representing a reference crank angle such as 180° and a crank angle signal (POS) representing a small crank angle such as 1°. These signals are shaped in the angle signal processing circuit 126.

The output from the knock sensor 44 is counted after using a software timer 127 (S timer).

The DIO 170 is arranged to receive outputs from an idle switch 148 (IDLE-SW), and a starter switch 152 (START-SW).

An explanation will now be given as to the pulse output circuit which is controlled in accordance with the results of the arithmetic operation performed by the CPU 102. An injector control circuit 134 (INJC) converts the digital value into a pulse signal as a result of the arithmetic operation. Thus, the INJC 134 produces a pulse having a pulse width corresponding to the rate of the fuel injection. This pulse is supplied to the injector 12 through the AND gate 136.

An ignition pulse generating circuit 138 (IGNC) has a register (ADV) for setting the ignition timing and a register (DWL) for setting the timing of the energization of the primary winding of the ignition coil 58. These data are set by the CPU 102. The IGNC 138 generates pulses in accordance with the set data and delivers the pulses through an AND gate 140 to an amplifier which energizes the ignition coil 58.

The rate of opening of the exhaust by-pass valve 68 is controlled by the pulse which is delivered by a control circuit (SCEC) 142 to the actuator 70 through an AND gate 143. The SCEC 142 has a register SECD for setting a value representing the duty of the pulse and a register SCECP for setting the period of repetition of the pulse.

The opening and closing of the intake by-pass valve 92 is controlled by a pulse which is delivered by a control circuit (SCIC) 144 to the actuator 90 through an AND gate 145. The SCIC 144 has a register SCICD for setting the value representing the duty (1 or 0) of the pulse.

An EGR control pulse generating circuit 154 (EGRC) for controlling the EGR control valve 60 has a register EGRD for setting a value representing the duty of the pulse and a register EGRP for setting a value representing the period of repetition of the pulse. The output pulse from the EGRC 154 is delivered through an AND gate 156 to a transistor (not shown) for energizing the EGR control valve 60.

The 1-bit signal is controlled by the circuit DIO 170. An IDLE-SW 148 and a START-SW signal 152 are its input signals. The DIO 170 has a register DDR for determining whether the terminal should be used as the input terminal or output terminal, and a register DOUT for latching the output data.

The register 160 is a register (MOD) adapted to hold commands for various states in the input/output circuit 108. For instance, by setting commands in this register, the AND gates 136, 140, 143, 145 and 156 are turned on or off. Thus, it is possible to control the stopping and starting of outputting signals by the circuits INJC 134, IGNC 138, SCEC 142, SCIC 144 and EGR 154 by setting the command in the MOD register 160.

Figure 6 shows the basic flow chart of the program system of the control circuit 100 shown in Figure 5. An administration program 600 for administrating a task group includes an initial processing program 202, a knock signal processing program 205, an interruption processing program 206, a macro processing program 228 and a task dispatcher 208. The initial processing program 202 is a program for effecting pre-processing for operating the microcomputer. This program makes processing operations such as the clearing contents of the RAM 106, the setting of initial values of registers in the input/output interface circuit 108 and deriving input information for preprocessing as necessary for control of the engine.

When an interrupt 500 occurs, determination is made at the next step 502 as to whether the interruption demand is NMI or IRQ. Where the interrupt demand is NMI, a knock signal processing program 205 is executed at the next step. The interrupt processing program receives various interrupts and makes an analysis of the reasons of the interrupts. The program 206 then delivers to the task dispatcher 208 starting demands for starting necessary tasks in the task groups 610 and 624.

In the initial interrupt processing operation 602 (referred to as the INTL interrupt) of the interrupt process, the program 206 produces, in accordance with the initial interrupt signal generated in synchronism with the

engine operation, initial interrupts of a number which is a half of the number of cylinders per crank shaft revolution of the engine. In the case of a four-cylinder engine, two initial interrupt demands are generated for each crank shaft revolution. The EGI task 612 calculates the fuel injection time in accordance with these initial interrupts and sets the thus calculated injection time in the register of the INJC 134. An AD conversion interrupt processing 604 makes clocks the input point to the multiplexer 120 in relation to the ADC 122 and starts the A-D conversion. After the completion of the conversion, the process 604 produces an ADCl interrupt.

The ADC 128 is used for the input AFS and produces an ADC2 interrupt after the completion of the conversion. These interrupts are used only before cranking.

Thereafter, the interval (INTV) interrupt procressing program 606 produces an INTV interrupt signal at a period set in the INTV register, e.g. every 10 m sec. This signal is used as the basic signal for monitoring the tasks which are to be started at predetermined periods. The renewal of a software timer is effected by this interrupt signal, to initiate the task the operation period of which is reached.

Task numbers representing preference are alloted to tasks in the task group. Each task may belong to any one of the task levels 0 to 2. The tasks belonging to the level 0 include an air signal processing task (referred to as AS task) 610, a fuel injection control task (IGN) 612, an ignition timing control task (IGN) 613 and a supercharger control task (SC task) 614. Also, tasks belonging to the level 1 include an ADI input task (referred to as ADINI task) 616, an 02 feedback task (02 F/B task) 617 and a time coefficient processing task (referred to as AFSIA task) 618. Further, tasks belonging to the level 2 include an exhaust gas recirculation control task (referred to as EGR task) 620, a correction calculation task (HOSEI task) 622 and a start preprocessing task (INSTRT task) 624.

The allotting of task levels and task functions are summarized in Table 1. As will be seen from Table 1, the starting periods of various tasks arranged to be started by various interrupts are determined beforehand. This information is stored in the ROM 104.

The task dispatcher 208 receives the starting demands of the various interrupts referenced above and determines the time of occupation of the CPU 102 in accordance with the order of preference

TABLE 1

Allotment of task level and task functions of tasks

level	program name	task No.	function	starting period
0	OS		engine speed interrupt control other OS processings	minimum 5 ms
	AS	0	prevention of pick-up of v calculation of v^2 integration and mean calculation of v^2 acceleration control fuel cut-off	10 ms
0	EGI	1	fuel injection time control CO control	20 ms
	IGN	2	ignition timing control, control of timing of electric voltage source	20 ms
	SC	3	control of exhaust by-pass valve control of intake by-pass valve	20 ms
	ADINI	5	AD converter 1 input, calibration, filtering	50 ms
1	AFSIA	6	after start, after idle, after acceleration, control of time coefficient	120 ms
	EGR	9	control of exhaust gas recirculation	320 ms
2	HOSEI	10	calculation of correction coefficient	320 ms
	ISTRAT	11	calculation of initial value of EGI observation of starter switch (ON) start and stop of soft timer start of fuel pump 1/OLSI start	30 ms

allotted to the tasks corresponding to the starting demands.

Figures 7 and 8 show a processing flow chart of the task dispatcher. Referring to Figure 7, as the processing of the task dispatcher program is commenced at step 300, a determination is made at step 302 as to whether any tasks belonging to the level ℓ are being executed. Namely, if the status of the execution bit is "1", this means that the task dispatcher 208 has not yet received the task completion report from the macro-processing program 228, i.e. that the task under execution has been interrupted by an interrupt having a higher preference. Therefore, when a flag "1" is set as the execution bit, the process jumps to the step 314 to start again the interrupted task.

On the contrary, when the flag "1" is not set as the execution bit, i.e. when the execution bit is reset, the process is shifted to the step 304 to make a determination as to whether there is any task waiting for the starting in the level ℓ. Namely, the starting bits of the level ℓ are searched in accordance with the order of preference of execution. If no flag "1" is set as the starting bit belonging to the task level ℓ, the process is shifted to the step 306 to effect the renewal of the task level. Namely, an increment of +1 is effected to provide a new task level $\ell + 1$. After the renewal of the task level in the step 306, the process proceeds to the step 308 where a determination is made as to whether all the levels of the task level have been checked or not. Where the check of all levels has not been completed, i.e. where ℓ does not equal "2", the process is returned to the step 302 to repeat the above-described procedure. On the contrary, if the completion of the check of all levels is confirmed at the step 308, the process proceeds to the step 310 to allow an interrupt to occur. Namely, an interrupt is prevented in the process between the steps 302 and 308, and the inhibiting of the interrupt is removed in the step 310. Then, the process proceeds to the step 312 to wait for the next interrupt.

If there is any task awaiting execution at the task level ℓ in the step 304, i.e. if the flag "1" is set as the starting bit belonging to the task level ℓ, the process proceeds to step 400 (Figure 8). In the loop of the steps 500 and 502, a search is made in accordance with the order of preference to find any flag "1" set as the starting bit of the task level ℓ. If any starting bit having the flag "1" is found, the process proceeds to the step 404 in which the starting bit having the flag "1" is reset and the flag "1" is set in the execution bit (hereinafter referred to as an R bit) of the corresponding task level ℓ. Furthermore, the step 406 indexes the starting task number and the start address information of the corresponding starting task is derived from the start address table set in the RAM 106 in the step 408.

Then, at the step 410, a determination is made as to whether the corresponding starting task is to be executed or not. More specifically, a decision is made as to whether the execution of the task is unnecessary if the desired start address information takes a specific value such as "0". This determination is necessary for providing the functions of only selected tasks, the selection being made according to the type of engine.

Where a decision is made at the step 410 to stop the execution of the corresponding task, the process proceeds to the step 414 to reset the R bit of the corresponding task level ℓ. The process is then returned to the step 302 where a determination is made as to whether the task level ℓ is being suspended. There is a possibility that a plurality of starting bits have flags. Therefore, the process proceeds to the step 302 only after resetting of the R bit in the step 414.

On the other hand, when a determination at the step 410 is carried out as to the execution of the task, the process proceeds to the step 412 and executes the task later.

Figure 9 shows the relationship between the speed of rotation of the supercharger NS and the stroke or opening degree of the intake by-pass valve (SS) and the exhaust by-pass valve (Sc) when the exhaust by-pass valve is fully closed whilst the speed of the supercharger is still low, all of the exhaust gas being supplied to the turbine to obtain a supercharging effect on the engine.

As the speed of rotation Ns of the supercharger exceeds a predetermined level N_2, the opening degree, Sc of the exhaust by-pass valve 68 is increased in accordance with an increase in the speed of rotation of the supercharger, to suppress the increase of the supercharging pressure. The exhaust by-pass valve 68 is fully opened when the speed of the supercharger is increased to N_3, so that damage to the engine due to an excessive supercharging pressure is avoided.

Feedback control is effected at a predetermined width as to the opening degree of the exhaust by-pass valve 68, in accordance with the state of occurrence of knocking in the engine.

The intake by-pass valve 92 is fully opened when the speed of rotation Ns of the supercharger is below a predetermined level N_1 ($N_1 < N_2$), in order to prevent intake air from flowing through the compressor 66 in the region of engine operation where no supercharging effect is available, to thereby decrease the resistance to the flow of intake air.

When the speed of rotation of the supercharger is increased beyond the normal speed to an abnormally high speed N_4, the intake by-pass valve 92 is fully opened to protect the engine.

It is possible to arrange the intake by-pass valve 92 such that it is normally opened and closed only when the solenoid 93 is energized, as shown in Figure 2. This arrangement ensures safety because no substantial problem arises even when a fault occurs in the control circuit or the solenoid 93 e.g. a short-circuit in the coil.

The above-described control of the engine applies to the steady state condition of the engine. In the transient period of engine operation, control is effected in a manner shown in Figure 10. During the acceleration period ⓐ, the intake and exhaust by-pass valve are closed for a predetermined time in order to assist in the smooth acceleration of the engine. However, when the engine is accelerated from a state of high supercharging pressure, the degree of opening of the exhaust by-pass valve 68 is controlled so as to

suppress the rate of increase of the compressor speed Nc to thereby prevent the breakdown of the engine due to an abrupt increase of the supercharging pressure. The details of this control will be explained later. During deceleration Ⓑ, the intake and exhaust by-pass valves are opened for a predetermined time.

Figure 11 shows a compressor graphical map of the supercharger and the operation curve of the same during full throttle opening operation of the engine. Symbols NE and N represent, respectively, the revolution speed of the engine and the efficiency of the supercharger. A broken line curve S shows the surging line. In the steady state condition of engine operation, the supercharging pressure (pressure ratio) is controlled in relation to the flow rate Q_a of air in accordance with the characteristic curve A.

In the region to the left of the surge line S, the separation of air from the surface of the impeller of the compressor 66 takes place to generate large noise. This pheonomenon may lead to a breakdown of the impeller. It is therefore, necessary to prevent the operation state from occurring in the region to the left of the surge line S.

For instance, the air flow rate Q_a is decreased as the engine is decelerated after an acceleration in the characteristic B. If deceleration is started from the state in which the supercharging pressure is about 350 mm Hg, the flow rate Q_a of intake air is decreased while the supercharging pressure provided by the compressor 66 is not decreased, as is shown by the curve C_1, so that the operational state will pass into the region on the left of the surge line S.

In order to prevent this from happening, it is necessary to decelerate the compressor 66 as quickly as possible as shown by the characteristic curve C_2. This can be best achieved by fully opening the exhaust by-pass valve 68 in order to release the exhaust gas coming into the turbine case 62T while permitting the intake air to by-pass the compressor 66.

If the exhaust by-pass valve 68 is fully closed during the acceleration to high-speed running, the supercharger will be accelerated to an excessively high speed as shown by the curve C_3, so that it is preferable to open the by-pass valve 68 to realize the characteristic as shown by the curve C_4.

With reference now to Figure 12, the output signal from the knock sensor includes, as will be seen from the waveform (F), knock signals such as a light knock signal F_1 and a medium sized knock signal F_2, a spurious signal z and an ignition signal noise Ig. A processing circuit is provided to pick up only the knock signals F out of these signals in order to obtain a pulse train signal KNCK, which effectively detects only the signals F_1 and F_2.

Figure 13 shows a program for processing of the knock signals KNCK. The CPU 102 conducts a series of operations such as detecting the pulse train signal KNCK, generation of an interruption NMI in synchronization with the first pulse train, counting of the software timer 127 (S timer), counting the number of pulses of the pulse train KNCK counted during starting of the S timer and an arithmetic operation for optimizing the supercharging pressure in accordance with the counted value.

As the interrupt NMI takes place at the step 521, a counter CNTR (not shown) in the RAM 106 starts the counting at step 522. The contents of the counter CNTR are increased by +1 and renewed at each time of receipt of the pulse of the knock signal. Then, at the next step 523, a determination is made as to whether the S timer 127 has been set or not, by means of the flag.

However, since the S-timer is not set in the case where no knocking takes place, the process proceeds to a step 524 at the moment at which the first pulse of the knock signal KNCK is detected, and a timer set execution report is made. Then, at a step 525, the S-timer is started by the first pulse of the knock signal KNCK and the contents of the same are renewed. Then, at a step 526, a determination is made as to whether the contents of the S-timer have reached a predetermined value.

Where the predetermined value has not been reached, the process returns to the step 525 so that the contents of the S-timer are renewed. During the starting of the S-timer, renewal of the contents of this timer is effected by a loop constituted by the steps 525 and 526. During the starting of the S-timer, pulses of a number corresponding to the degree of the knocking are fed into the counter CNTR, in the form of a pulse train signal KNCK. The second pulse of the pulse train signal KNCK also takes the place of the interrupt MN1. The contents of the counter CNTR are renewed at step 522, and at the next step 523, as the S timer 127 has been set, the process jumps to the step 533, then returns to the loop consisting of steps 525 and 526.

In the same way, at the third or further pulse of the pulse train signal KNCK, an interrupt NM1 occurs. Then, as it is determined that the contents of the S-timer have reached the predetermined value at the step 526, the process proceeds to a step 527 to make the report of completion of the timer execution.

Then, at the step 529, the amount ΔE of correction to the degree of opening of the exhaust by-pass valve 68 is calculated in accordance with the relationship $\Delta E = f$ (CNTR). Thus, a correction is made to increase the opening of the exhaust by-pass valve 68 as knocking increases.

Further, at the step 531, the contents of the counter CNTR and the S-timer are cleared, in order to prepare for the occurrence of further knocking and a correction execution report is made at the next step 532 for the task scheduler 508 to demand the execution of correction for knocking in the supercharger control program of Figure 14. After the completion of the correction execution report, the process is returned from the step 533 to the step 500 in Figure 6 to receive a new interrupt.

Explanation will now be given regarding the processing of the air flow rate signal in the As task 610.

Representing the flow rate (flow rate by mass) of the intake air by g_A, the output voltage of th hot wir element 24 is expressed by the following equation:-

$$V = \sqrt{C_1 + C_2\sqrt{q_A}} \qquad \text{.............. (1)}$$

Representing the output voltage V obtained when the revolution speed N is zero and flow rate q_A is zero by $V = V_o$, the equation (1) can be rewritten as follows:-

$$q_A = \frac{1}{C_2^2}(V^2 - V_0^2)^2 \qquad \text{.............. (2)}$$

Thus, the mass flow rate q_A of air at each moment is determined by the equation (2). Therefore, the mean air flow rate in each suction stroke of the engine is given by the following equation:-

$$Q_A = \frac{q_{A1} + q_{A2} + \text{.......} q_{An}}{n} = \frac{\sum_{n=1}^{n} q_{An}}{n} \qquad \text{.......... (3)}$$

The As task 610 performs the calculation of the rate of change of Q_A within a predetermined period of time in order to determine whether the engine is accelerating or decelerating. Then, during acceleration or deceleration, a necessary correction is made directly or in another task such as the fuel injection controlling task 612.

Figure 14 shows the processing program of the supercharger controlling task 614. At first, a determination is made as to whether the engine is in the accelerating condition or not, at a step 702. If the rate of change of Q_A within a predetermined period exceeds a predetermined value, it is determined that the engine is in the accelerating condition. This determination is made by processing the As task 610 and taking the result of this process. Where the engine is not in the accelerating condition, a determination is made at the next step 704 as to whether the engine is in the state of quick deceleration. It is determined that the engine is in the state of quick deceleration on condition of generation of the output from the IDLE-SW 148 as full closing of the throttle valve 14.

If the engine is not in the state of acceleration or in the state of deceleration, a calculation of basic by-pass valve opening is made at a step 706. After a determination of the speed of rotation Nc of the supercharger, the opening of the exhaust by-pass valve is investigated from the table stored in the ROM 104 to provide the characteristics shown in Figure 9. The actual table is constructed to provide the on duty of the pulse currents applied to the transistors of the actuators 70 in place of the opening of the exhaust by-pass valve 68.

Then, a determination is made in a step 708 as to whether knocking is taking place. When knocking occurs, a correction of the opening of the exhaust by-pass valve 68 is made in accordance with the result of the flow shown in Figure 13, at a step 710.

Then, at a step 712, the speed of rotation Nc of the supercharger is determined and the opening of the intake by-pass valve 92 is investigated from the table stored in the ROM 104 providing the characteristics shown in Figure 9.

The pulse for energizing the actuator 70 is delivered at a step 714, whilst the pulse for energizing the actuator 90 is delivered at a step 716. Then, the process proceeds to task completion in a step 718.

If it is determined at the step 702 that the engine is in the state of acceleration, the speed of rotation Nc of the supercharger is determined. If the speed of rotation Nc does not reach 70,000 R.P.M. the exhaust by-pass valve 68 is fully closed for a period of t_1 m sec at a step 722 and then at a step 724, the intake by-pass valve 92 is fully closed for a period of t_2 m sec as shown in Figure 10. Then, the valves are actuated in accordance with this result at the steps 714 and 716, to thereby assist the acceleration of the engine.

If it is determined at a step 720 that the speed of rotation Nc of the supercharger is not lower than 70,000 R.P.M., the opening of the exhaust by-pass valve 68 is controlled at a step 726 whilst maintaining the rate ΔNc of increase of the speed of rotation Nc of the supercharger within a predetermined range. The purpose of this operation is to avoid an abnormal increase of the engine speed attributable to the closing of the exhaust by-pass valve 68 during high-speed running of the engine.

If it is determined at the step 704 that the engine is in the decelerating state, the process proceeds to a step 728 in which the exhaust by-pass valve 68 is fully opened for t_3 m sec and the intake by-pass valve 92 is fully opened for t_4 m sec to prevent the generation of surging.

In the above-described embodiment, the intake and exhaust by-pass valves are actuated by actuators having solenoids. It will be appreciated that other types of actuators may be used. For instance, it is possible to use hydraulic pneumatic pressure (vacuum) as the actuating medium. In such a case, the level of th actuating power is controlled by a solenoid valve which, in turn, is energized by a pulse signal under a duty control.

Furthermore, in the place of a knock sensor, it is possible to use suitable means for detecting the combustion pressure in the combustion chamber and for feeding back the result of the detection.

The speed of rotation of the supercharger can be detected by optical means including a light emitting element, light receiving element and a light reflecting body attached to the shaft of the supercharger.

CLAIMS

1. A supercharger control apparatus for use with an exhaust gas turbine system driven by the energy of the exhaust gas from an internal combustion engine and being coupled with a supercharger compressor driven by said turbine, and which is coupled to a fluid intake system of the engine to supercharge the engine, the system having a controllable exhaust gas by-pass mechanism for controlling the supply of exhaust gas to said turbine; said supercharger control apparatus including:
(a) first means for monitoring the operation of said engine;
(b) second means for monitoring a prescribed operational characteristic of said supercharger;
(c) third means for storing data representative of the degree to which said exhaust by-pass mechanism by-passes exhaust gas from said turbine in relation to the state of operation of said engine and said supercharger;
(d) fourth means, coupled to said first, second and third means, for generating control signals for controlling the operation of said exhaust gas by-pass mechanism in response to data stored by said third means and accessed in accordance with outputs of said first and second means; and
(e) fifth means for coupling control signals generated by said fourth means to said exhaust gas by-pass mechanism and thereby control the supply of exhaust gas to said turbine.

2. A supercharger control apparatus according to Claim 1, wherein said second means includes means for monitoring the speed of rotation of said supercharger, wherein said controllable exhaust gas by-pass mechanism comprises an exhaust by-pass valve, and wherein said third means stores data representative of the degree of opening of said exhaust by-pass valve in relation to the speed of rotation of said supercharger, whereby said exhaust gas by-pass valve is controllably opened by the operation of said fourth and fifth means in response to the speed of rotation of said supercharger.

3. A supercharger control apparatus according to Claim 2, wherein said first means includes means for detecting knocking of the engine and wherein said third means stores correction data for correcting the degree of opening of said exhaust by-pass valve in accordance with the degree of knocking of the engine.

4. A supercharger control apparatus according to Claim 2 or 3, wherein said first means includes means for detecting the acceleration of the engine and said third means stores data representative of the closing of said exhaust by-pass valve for a prescribed period of time in accordance with the acceleration of the engine.

5. A supercharger control apparatus according to any one of the preceding Claims 2 to 4, wherein said first means includes means for detecting the deceleration of the engine and said third means stores data representative of the opening of said exhaust by-pass valve for a prescribed period of time in accordance with the deceleration of the engine.

6. A supercharger control apparatus according to Claim 1, wherein said fluid intake system includes a controllable intake by-pass mechanism by-passing said compressor for controlling the rate of supply of fluid to said internal combustion engine, wherein said third means stores data representative of the degree to which said intake by-pass mechanism supplies air to said internal combustion engine in relation to the state of operation of the engine and the supercharger, wherein said fourth means generates control signals for controlling the operation of said intake by-pass mechanism in response to data stored by said third means and accessed in accordance with outputs of said first and second means, and wherein said fifth means couples control signals generated by said fourth means to said controllable intake by-pass mechanism to thereby control the rate of supply of fluid to said internal combustion engine.

7. A supercharger control apparatus according to Claim 6, wherein said second means includes means for monitoring the revolution speed of said supercharger, wherein said controllable exhaust gas by-pass mechanism and said intake by-pass mechanism respectively comprise an exhaust by-pass valve and an intake by-pass valve, and wherein said third means stores data representative of the degree of opening of said valves in relation to the revolution speed of said supercharger, whereby said valves are controllably opened in response to the speed of rotation of said supercharger in accordance with the operation of said fourth and fifth means.

8. A supercharger control apparatus according to Claim 7, wherein said first means comprises means for detecting the knocking of the engine and wherein said third means stores correction data for correcting the degree of opening of said exhaust by-pass valve in accordance with the degree of knocking of the engine.

9. A supercharger control apparatus according to Claim 7 or 8, wherein said first means includes means for detecting the acceleration of the engine and wherein said third means stores data representative of the closing of said intake and exhaust by-pass valves for respective prescribed periods of time in accordance with the acceleration of the engine.

10. A supercharger control apparatus according to any one of the preceding Claims 7 to 9, wherein said first means includes means for detecting the deceleration of the engine and said third means stores data representative of the opening of said intake and exhaust by-pass valves for respective prescribed periods of time in accordance with the deceleration of the engine.

11. A supercharger control apparatus constructed and arranged to operate substantially as herein described with reference to and as illustrated in the accompanying drawings.

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